# Zooplankton and Phytoplankton Contributors to Bioluminescence in Monterey Bay

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## LONG-TERM GOALS

My long term goal is to understand and predict the distribution of marine bioluminescence, using the most advanced technology available for measuring light in the sea. I am especially interested in the organisms that cause luminescence, and their relative contributions to the oceanic light-field.

## OBJECTIVES

The objectives of this study are to use our data gathered from autonomous underwater vehicles and other platforms to develop an understanding of the scales (space and time) over which bioluminescence varies in coastal environments. I hope to understand large-scale bioluminescence features in the context of the physics, chemistry, and biology of the environment, and to examine patchiness of bioluminescence using fine-scale measurements. With the combination of these two types of data, we will be better equipped to design sampling programs in such a way that meaningful prediction may be accomplished. Because the ultimate source of bioluminescence is the plankton populations, I am keenly interested in integrating accurate measurements of zoo- and phytoplankton into our otherwise instrument-based programs. Another important objective is to work iteratively with modellers, exchanging data back and forth to improve our ability to predict distributions.

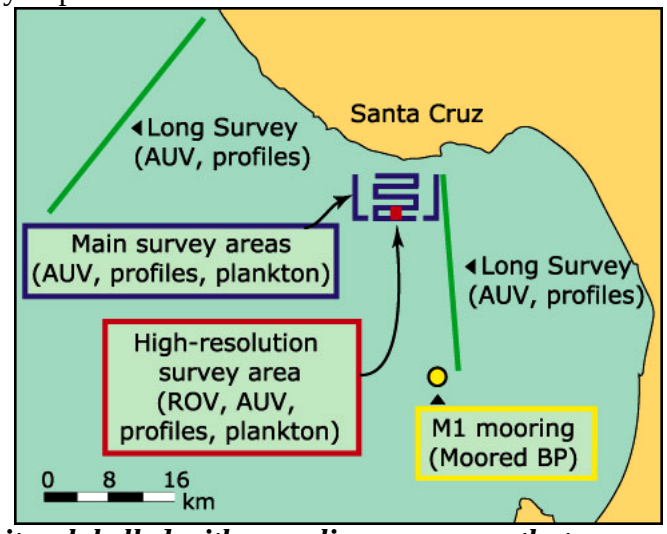


***Figure 1. The study sites, labelled with sampling programs that were successfully completed.***

## APPROACH

During our August 2000 field season, we operated on scales ranging from > 20 km to less than 1 km (Figure 1). Large scale transects (green) were used to provide a picture of the area surrounding the study site — maximizing the variability in the luminescent signals and sources detected. These long-scale

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14. ABSTRACT
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15. SUBJECT TERMS

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transects have revealed the most about luminescence distributions, and we have focused much of our subsequent analysis on these 22km segments. Fine-scale surveys (intensive sampling within a 1 km square; red) were repeated several times during particular nights to examine fine structure and rapid changes in bioluminescence distributions. Sampling was coordinated with many instruments, platforms, and ships. Stationed on the R/V Pt. Sur were (a) an optical profiling cage, which measured temperature, luminescence, absorption, scattering, fluorescence, and optical backscatter (OBS), and (b) an autonomous underwater vehicle (AUV), which measured luminescence, fluorescence, OBS, temperature and salinity. We also repeated profiling along the long survey line in December, as a means of quantifying our bathyphotometer's capture efficiency, and to get baseline data on seasonal variation.

Zooplankton and phytoplankton samples were collected and enumerated by microscopic examination, and pigments and nutrients were analyzed in the lab from preserved water samples. Fine-scale measurements were conducted with the above platforms, with the addition of a bathyphotometer and low-light imaging system mounted aboard the ROV Ventana, in conjunction with Edie Widder. A time-series was also obtained from an instrument mounted on the M1 mooring.

## WORK COMPLETED

In the year following the field season we have focused on data analysis, write up, and organization of future programs. In the wake of the cruise, we have corrected, calibrated, and analyzed the data from 67 successful AUV runs. These data have been conveyed to several modelling groups, who have incorporated the results into their regional physical models, and the data have been archived on a master CD that includes data from other investigators in the MUSE program. We have completed counting the zooplankton from all the vertical profiles and from the high-resolution ROV surveys, and analyzed the nutrients from the profiling stations. We have done detailed analysis of the fine-scale surveys, to provide the most accurate view to date of the scales of patchiness, and to examine the repeatability of these high-resolution surveys. We have also analyzed the large scale transects with regard to the physical and currents (ADCP) data collected.

A follow-up cruise was conducted in December to analyze the plankton capture efficiencies of our bathyphotometers and to compare the bioluminescence intensities from the winter with those measured in the late summer. The plankton samples from this experiment have been counted, and the desired correlations have been achieved.


***Figure 2. The San Diego Workshop subsection of the Bioluminescence Web Page.***

I have also continued to update and maintain the Bioluminescence Web Page, which is the top-ranked source of bioluminescence information on the internet (sources: Google, DirectHit). In the past year, this site has been the subject of profiles in *Science* Magazine, *Natural History*, *New Scientist*, and *Scientific America*. A new section has been added (Figure 2), which includes the results and discussion from an ONR-sponsored bioluminescence workshop, which took place in San Diego last year

(http://lifesci.ucsb.edu/~biolum/sdworkshop/). This site makes scientific discussions (and reliable information about bioluminescence in general) available to a large audience.

Two bioluminescence data workshops have been hosted at MBARI since the field season. The goals have been to coordinate the analysis and write-up and the data, and to plan future work in this area. Both workshops were very successful, with spirited exchange of ideas between more than 20 participants — those most closely involved in data collection and work-up.

## RESULTS

*December cruise* - Our second cruise gave interesting results with regard to the seasonality of bioluminescence in coastal oceans. As shown in Figure 3, the bioluminescence signal varied only slightly between the first (237) and last (245) days of our August cruise. In contrast, a profile taken at the same location three months later was dramatically lower. This demonstrates that the short-term changes may be predictable to an order of magnitude, but results from one sampling time can not readily be extrapolated to other times of the year. A second finding of the December cruise was that our newly designed bathyphotometers captured amounts of copepods comparable to our plankton samplers, giving us confidence in the general usability of small sensors.

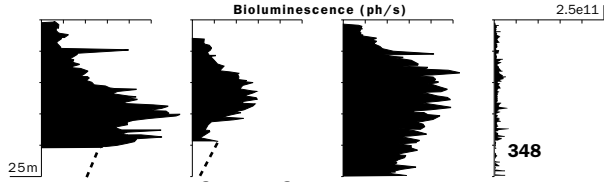


***Figure 3. Variability in three vertical profiles of bioluminescence taken in August 2000, compared with a profile taken at the same location in December.***
***[August profiles vary by 2-4 times, but the December profile is much lower — almost a flat line]***

As part of our high-resolution mapping, we attempted to determine how much confidence we might place in the existence of a feature which was seen during a particluar leg of a run. To test this, we ran transects out and back along the same line at one depth, instead of yo-yoing. The results from several of these trials indicate that the watermass variability is being accurately captured by our instruments and sampling schemes.

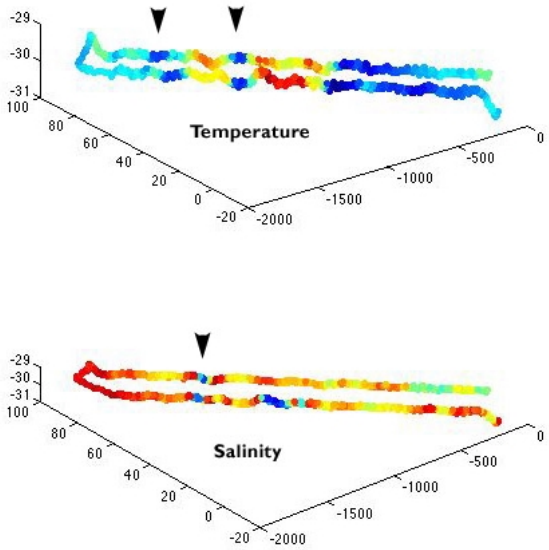


***Figure 4. T and S features persisted during repeated runs through a parcel of water.***

*Plankton distributions* - Our plankton sampling successfully established the presence of several bioluminescent species which we believe were responsible for the majority of bioluminescence detected by our instruments. Dominant phytoplankton genera included *Protoperidinium*, *Noctiluca*, and a possibly luminous species of *Alexandrium*. Luminous zooplankton included larvaceans in great numbers, and luminous copepods.

*Large-scale transects* - Our long transects (>22 km) have provided a wealth of data, because they covered scales appropriate for visualizing the limits of bioluminescent features (kilometer horizontal, 8 meters vertical). We have been correlating the presence of high luminescence with (1) the origins of the water masses in which they reside, (2) frontal features, and (3) circulation patterns, as illustrated by models and by actual current measurements (ADCP, pre-processed by Curt Collins; Figure 5).

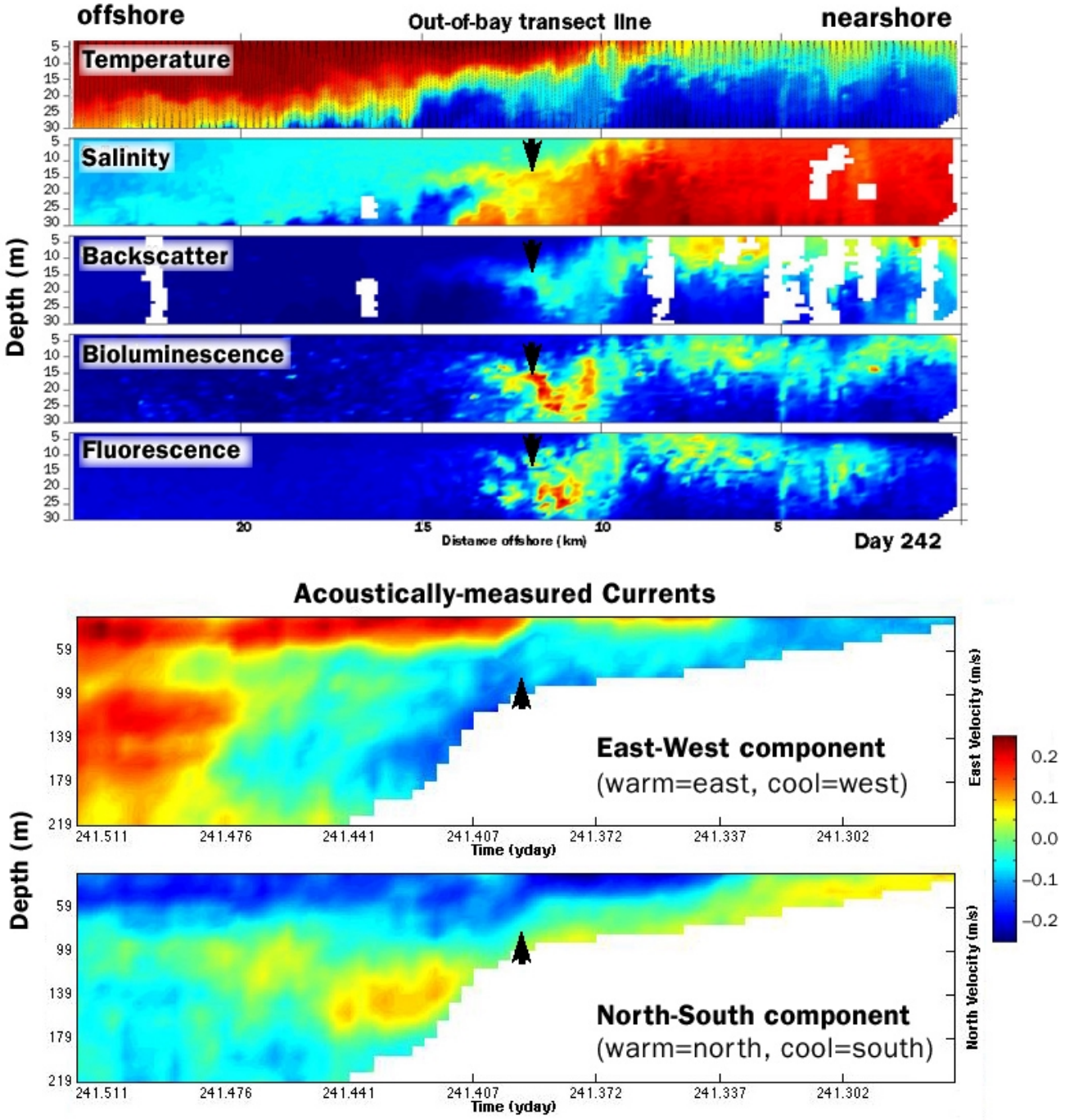


***Figure 5. Correlation of physical features with bioluminescence and other measurements.***
**[ bioluminescence distributions show dramatic increase at a frontal feature]**

## IMPACT/APPLICATION

Our results have had direct implications for the design of future sampling protocols. In particular, long transects are best for resolving features at model-relevant scales. In the temporal sense, it appears that variability on the scale of a week, even in the presence of large changes in the wind field (not shown), are much less important than variations over seasons. Fronts appear to be strong factors in determining the accumulation and distribution of bioluminescent organisms. When present, dinoflagellates contribute to the majority of the bulk bioluminescence signal, but zooplankton are the dominant sources in deeper water and further offshore.

## TRANSITIONS

We have not yet had any instrumentation transitions arise from this project. Data have been widely distributed and shared with other researchers and modellers.

## RELATED PROJECTS

ONR-supported work of Mark Moline, Edith Widder, James Case, and Christy Herren are all intimately linked with the sampling and analysis which I have described. Dennis McGillicuddy and in particular Igor Shulman have integrated our data into instructive physical models of the Monterey Bay.
The entire project was part of the MUSE project, most closely associated with the work of Francisco Chavez and Ken Johnson of MBARI. AUV equipment, ship time, and expertise were sponsored through ONR grants to Jim Bellingham.

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